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# Constraints on the Neutrino Mass from SZ Surveys

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**ABSTRACT**

Statistical measures of galaxy clusters are sensitive to neutrino masses in the sub-eV range. We explore the possibility of using cluster number counts from the ongoing PLANCK/SZ and future cosmic-variance-limited surveys to constrain neutrino masses from CMB data alone. The precision with which the total neutrino mass can be determined from SZ number counts is limited mostly by uncertainties in the cluster mass function and intracluster gas evolution; these are explicitly accounted for in our analysis. We find that projected results from the PLANCK/SZ survey can be used to determine the total neutrino mass with a $(1\sigma)$ uncertainty of $0.06$ eV, assuming it is in the range $0.1-0.3$ eV, and the survey detection limit is set at the $5\sigma$ significance level. Our results constitute a significant improvement on the limits expected from PLANCK/CMB lensing measurements, 0.15 eV. Based on expected results from future cosmic-variance-limited (CVL) SZ survey we predict a $1\sigma$ uncertainty of $0.04$ eV, a level comparable to that expected when CMB lensing extraction is carried out with the same experiment. A few percent uncertainty in the mass function parameters could result in up to a factor $\sim 2-3$ degradation of our PLANCK and CVL forecasts. Our analysis shows that cluster number counts provide a viable complementary cosmological probe to CMB lensing constraints on the total neutrino mass.

## 1 INTRODUCTION

CMB measurements already placed meaningful upper limits on the total neutrino mass from its impact on the early integrated Sachs Wolfe (ISW) effect. The energy scale of recombination, $\sim 0.3$ eV, sets the value of this upper limit; if the total neutrino mass is larger than this value, then neutrinos are non-relativistic and do not contribute to the decay of gravitational potentials shortly after recombination. If, on the other hand, the total mass is lower they constitute a relativistic component that contributes to the decay of linear gravitational potentials, which causes a net change in the temperature of the CMB towards these gravitational wells.

Measurements of CMB polarization open yet another window on neutrino masses via CMB lensing by the intervening large scale structure at redshifts of a few. Multiple ongoing ground-based CMB experiments are targeting this lensing-induced B-mode signal which is expected to peak on a few arcminute scales , $l \sim 1000$, far away from the predicted, much weaker primordial (inflation-induced) B-mode signal that is expected to peak at degree scales, $l \sim 100$. It has been shown that applying optimal estimators to CMB temperature and polarization maps one can recover the lensing potential to the precision that will allow constraining the total neutrino mass to the $0.04$ eV level (Kaplinghat, Knox & Song, 2003) with a cosmic-variance-limited (CVL) CMB experiment, assuming full-sky coverage, no foregrounds, and no source of non-gaussianity other than the lensing of the CMB, a feature on which the optimal filters rely. In practice, it is unlikely that all these conditions will be fully satisfied and in that sense the frequently-quoted value $0.04$ eV is quite likely too optimistic. Yet, this is currently the most promising CMB-based probe for neutrino mass inference.

Other cosmological neutrino probes can constrain their masses to varying degrees, e.g. Abazajian et al. (2011), Wong (2011), and supplementary laboratory experiments which are expected to reach the $\sim$0.2 eV sensitivity. Complementary cosmological probes of neutrino masses include: CMB temperature anisotropy (e.g., MacTavish et al. 2006, Komatsu et al. 2010), weak lensing and shear maps (e.g., Cooray 1999, Abazajian & Dodelson 2003, Song & Knox2004, Hannestad, Tu & Wong 2006, Kitching et al. 2008, Namikawa et al. 2010), galaxy (Hu, Eisenstein & Tegmark 1998, Hannestad 2003, Tegmark et al. 2004, Tegmark et al. 2006, Thomas, Abdalla & Lahav 2010 ) and Ly$\alpha$ surveys (Croft, Hu & Dave 1999, Goobar et al. 2006, Seljak, Slosar & McDonnald 2006, Gratton, Lewis & Efstathiou 2008). Joint of these different datasets will meaningfully constrain the neutrino masses Joudaki & Kaplinghat (2011). In order to asses the relative importance of

the yields of these various probes, the upper limits that they set should be compared to the lower limits obtained on neutrino masses from neutrino oscillation experiments. The observed level of neutrino oscillations implies that at least one of the neutrinos is 0.05 eV or heavier. This picture corresponds to the 'normal hierarchy'. In the 'inverted hierarchy' two neutrino masses are each above 0.05 eV. This implies that the lowest bound on the total neutrino mass lies in the range 0.05-0.10 eV, which sets the benchmark level for determining the hierarchy, ultimately allowing rejection of one of these neutrino mass models. The goal is therefore to push the (cosmological) upper neutrino mass limits down below 0.05 eV.

Cluster number counts are yet another useful probe of neutrino masses. This is due to the fact that typical cluster scales are much smaller than the $\sim 150$ Mpc scale of linear dark matter halos that lens the CMB. In addition, cluster number counts are exponentially sensitive to $\sigma(M,z)$, the rms mass fluctuation on the cluster mass scale $M$ at redshift $z$, and since $\sigma(M,z)$ itself is exponentially sensitive to neutrino mass (via the growth function, see e.g. Eq.134 of Lesgourgues & Pastor 2006) this implies that cluster number counts should be a rather sensitive probe of neutrino masses, as has already been demonstrated, e.g., Wang et al. (2005), Shimon, Sadeh & Rephaeli (2011); hereafter, SSR, and recently also Carbone et al. (2011). While the latter work is also based on cluster number counts, our treatment here includes explicit accounting for uncertainties in the (all important) cluster mass function, and a wider range of fiducial neutrino masses (0.1-0.3 eV). Here we further explore the ability to strengthen the constraints on the neutrino mass from cluster number counts. We do so by parameterizing uncertainties in the halo mass function, which is the dominant source of modeling uncertainties. This important function, whose specific shape and normalization reflect the details of the growth of density fluctuations, and the non-linear hierarchical collapse and mergers of sub-structures, can be best studied by state-of-the-art large-volume hydrodynamical cosmological simulations. Although very advanced, currently available numerical codes predict a range of mass functions. At present, this mass function indeterminacy largely sets the precision limit of forecasting the total neutrino mass from cluster SZ number counts and power spectrum. In the first phase of our work (SSR) we considered highly degenerate nuisance parameter which greatly degraded our results. Aside from reconsidering this issue, in the current work we also include cluster sample variance errors (in addition to Poissonian noise), a more realistic intracluster (IC) gas profile, as well as gas evolution with cluster mass and redshift.

Our basic approach and details of the Fisher Matrix analysis are only briefly described here; a more extensive description can be found in SSR. In section 2 we discuss the impact of massive neutrinos on the LSS and cluster number counts, and briefly describe, in section 3, the Fisher matrix analysis used in this work. Our main results are presented in section 4, and further discussed in section 5.

## 2 NEUTRINO IMPACT ON GROWTH OF THE LSS

The evolution of structure in the matter-dominated era is embodied in the matter power spectrum,

$$P_m(k,z) = Ak^nT^2(k,z), \tag{1}$$

where $Ak^n$ is the primordial density fluctuation spectrum, with $A$ its overall normalization, $n$ is the tilt of the power spectrum, and $T(k,z) = T(M_\nu;k,z)$ is the transfer function. An important quantity gauging the amplitude of the processed power spectrum observed today is the mass variance parameter on a scale of $8\,\mathrm{Mpc\,h^{-1}}$,

$$\sigma_8^2 = \int_0^\infty P_m(k,z)W^2(kR)k^2\frac{dk}{2\pi^2}, \tag{2}$$

where $W(kR)$ is a window function, and $R = 8\,\mathrm{Mpc\,h^{-1}}$. The latter quantity incorporates the physics of neutrino damping; thus, $\sigma_8$ is a function of not only $A$ and $n$, but also of neutrino masses (via the transfer function), and indeed any other cosmological parameter which affects structure evolution on scales of few tens of Mpc and below. Because these scales are comparable to the typical scales of diffusion damping of density fluctuations by neutrinos with small masses, we expect that $M_\nu$ and $\sigma_8$ will be anti-correlated. Since the SZ signature is a strong function of $\sigma_8$, it is expected to be sensitive also to $M_\nu$. More generally, the mass variance on a physical scale $R$ and at redshift $z$ is

$$\sigma_R^2(z) = \int_0^\infty P_m(k,z)W^2(kR)k^2\frac{dk}{2\pi^2} \tag{3}$$

where the effective upper cutoff of the integral is $\sim R^{-1}$. For large $R$ there generally is little impact of $M_\nu$ on $\sigma_R$, but on cluster scales, where $R$ is 1 Mpc or smaller, the impact of non-vanishing $M_\nu$ on $\sigma_R$ is considerable. As we show below, the discriminative power of cluster number counts stems from the exponential dependence of the mass function on $\sigma_R$. In our numerical calculations of the SZ effect we employ a publically available code (Kiakotou, Elgaroy & Lahav 2007) to determine $T(k,z)$ assuming three degenerate neutrino masses, but we do use the default CAMB transfer function to calculate the primordial angular power spectrum of the CMB. This is warranted since the main difference between the two transfer functions is most apparent at large values of $k$.

The basic quantity which describes the number density of clusters as a function of their mass and redshift - basic properties by which clusters are identified - is the mass function. As will be shown later, the total neutrino mass can be derived from comparison of the observed number of clusters in a given redshift-bin to the number predicted from the mass function, $\frac{dn(M;z)}{dM}$. The latter function is defined in terms of the differential number of clusters in a volume element $dV$,

$$dN(M,z) = f_{sky}\frac{dn(M,z)}{dM}dVdM, \tag{4}$$

where $f_{sky}$ is the observed sky fraction, which for the two experiments discussed here is 0.65 when realistic masking of the galaxy is considered. The total number in a given interval $\Delta z$ around $z_i$ is

$$\Delta N(z_i) = f_{sky}\Delta z_i \frac{dV(z_i)}{dz}\int \frac{dn(M,z_i)}{dM}dM. \tag{5}$$

As noted earlier, the current most optimal determination of the mass function is from cosmological simulations. Here we adopt the mass function derived recently by Tinker et al. (2008) from a large set of dynamical cosmological simulations in the $\Lambda$CDM scenario. Expressing the mass function in the conventional form,

$$\frac{dn}{dM} = f(\sigma)\frac{\rho_m}{M}\frac{d\ln(\sigma^{-1})}{dM}, \tag{6}$$

these authors derived a fit of the form

$$f(\sigma) = A\left[\left(1+\frac{\sigma}{b}\right)^{-a}\right]e^{-\frac{c}{\sigma^2}}, \tag{7}$$

where the parameters $A$, $a$, $b$ and $c$ were the best-fits to the results of their simulations. The mass function does not have a universal form, a fact that becomes apparent by the deduced dependence of these fit parameters on both redshift and the overdensity at virialization, $\Delta_v$

$$\begin{aligned}
A &= A_0(1+z)^{-0.14}\\
a &= a_0(1+z)^{-0.06}\\
b &= b_0(1+z)^{-\alpha}\\
\log(\alpha) &= -\left(\frac{0.75}{\log(\Delta_v/75)}\right)^{1.2}\\
b_0 &= 1.0+(\log(\Delta_v)-1.6)^{-1.5}
\end{aligned} \tag{8}$$

where $c$ and $A_0$ are obtained from Table 2 of Tinker et al. (2008) which we also used in deriving fits for $a_0$ and $b_0$ as functions of $\Delta_v$. The following are very good fits for the relevant $\Delta_v < 400$ range

$$\begin{aligned}
a_0 &= 1.7678\alpha_1 - 0.5941\alpha_2\exp(-0.02924\Delta_v^{0.5967})\\
c &= 1.7077\alpha_3 - 0.7038\alpha_4\exp(-0.001\Delta_v^{1.079})
\end{aligned} \tag{9}$$

where $\alpha_1 - \alpha_4$ equal 1 in the fiducial (Tinker et al. 2008) model. In our analysis we include these four nuisance parameters to account for possible small uncertainties or biases in these parameters.

The SZ effect is a unique probe of cosmological parameters and cluster properties; its statistical diagnostic value is reflected through number counts and the power spectrum of the CMB anisotropy it induces. As we have stated already, the dependence of cluster number counts on the total neutrino mass, and an assessment of the feasibility of actually determining it from cluster surveys are our main objectives in this work. The details of the calculation of the statistical SZ signal from individual z-shells, i.e. clusters residing within a narrow redshift interval, follow those described in SSR. We adopt the spherical collapse model for cluster formation, and we relate the virial cluster mass to its radius using the standard relation.

DM profiles are assumed to have the the Navarro-Frenk-White (NFW; Navarro, Frenk & White 1995) form, with the mass-concentration relation $c(M,z)$ from Duffy et al. (2008). We assume a polytropic equation of state for IC gas with a polytropic index $\Gamma = 1.2$. The solution of the equation of hydrostatic equilibrium for a polytropic gas inside the potential well of a DM halo is (Ostriker, Bode & Babul 2005):

$$\rho(x) = \rho_0\left[1-\frac{B(\Gamma-1)}{\Gamma}\left(1-\frac{\ln(1+x)}{x}\right)\right]^{1/(\Gamma-1)} \tag{10}$$

where $x = r/r_s$, $r_s$ is the scale factor of the NFW density profile, $B$ is given by $B = 4\pi G\rho_s r_s^2\mu m_p/k_B T_0$ and $\mu m_p$ is the mean molecular weight. Further details of the IC gas model used in this work are given in Dvorkin, Rephaeli & Shimon (2012).

IC gass mass fraction is assumed to follow that of Vikhlinin et al. (2009) with a nuisance parameter in our analysis

$$f_g(M,z) = \alpha_5[0.125 + 0.037\log_{10}(M_{500}/M_{15})] \tag{11}$$

with fiducial value $\alpha_5 = 1$. Here $M_{500}/M_{15}$ is the total cluster mass enclosed in a sphere of overdensity of 500 in units of $10^{15}$ solar masses. The redshift dependence in Eq.(11) is that of $M_*$, defined such that for a fixed redshift the mass fluctuation $\sigma(M_*, z) = 1.686$. Under these assumptions we normalize the SZ power spectrum to conform with the value measured recently by SPT (Reichardt et al. 2011), $C_l = 3.65\mu K^2$ at $l = 3000$. We do so for each fiducial mass separately such that for each of the three fiducial values considered here (0.1, 0.2, and 0.3 eV) the power spectrum at $l = 3000$ is the same.

Nonetheless, the shape of the SZ power spectrum depends on the fiducial neutrino mass, but the power level at the relevant range $2000 < l < 3000$ is nearly the same, implying that a similar number of galaxy clusters is expected to be detected (for a fixed SPT level at $l = 3000$), resulting in neutrino mass uncertainties essentially independent on the assumed fiducial neutrino mass.

## 3 FISHER MATRIX ANALYSIS

Our cosmological model includes the normalization $A$ and tilt $n$ of the primordial scalar perturbations, neutrino mass $M_\nu$, matter, $\Omega_m$, and baryon, $\Omega_b$, density parameters, the Hubble parameter (scaled to 100 km/sec/Mpc) $h$, dark energy equation of state $w$, optical depth to reionization $\tau$, and the primordial helium abundance $Y_p$. The priors on the cosmological parameters are obtained from the primary and lensed sky observed with PLANCK and the CVL experiments, with the corresponding Fisher matrices denoted by $F^{pr}$ and $F^{LE}$, respectively. We also use the prior $H_0 = 71.0 \pm 2.5$ km/sec/Mpc. In calculating the Fisher matrix for the primary CMB (with and without lensing extraction, LE) we follow the standard approach which we do not reproduce here; details of the calculation can be found in, e.g., Lesgourgues et al. (2006). In addition to the above nine cosmological parameters we included two free parameters in the gas mass fraction Eq.(10) and four parameters to describe small departures from the values of Tinker et al. (2008; see our eqs. 8-9).

The likelihood function for cluster number counts would naively be written as a Poisson distribution involving the observed and theoretical number counts in redshift-shells (e.g., Holder, Haiman & Mohr 2001). In practice, however, for higher abundance clusters one has to include also the cluster correlation term that increases the naive sample bias (Hu & Kravtsov 2003). Our $5\sigma$ detection threshold guarantees that only the most massive clusters will be detected, rendering the effect of this extra term small; our estimations of neutrino mass uncertainty from the combined primordial CMB and number counts increase by only $10-15\%$ when including this extra term.

We set the shell-width to $\Delta z = 0.1$ which is safely larger than predicted photo-z redshift uncertainties which are at the $\sigma_z = 0.02(1+z)$ level. We found that increased refinement of the redshift bins essentially does not affect our results. This improvement never exceeds the $15\%$ level; therefore, we adopted $\Delta z = 0.1$. The cutoff on our cluster sample was set at $z_{max} = 1.0$ because we found that removing individual redshift shells (with a fixed CMB prior on the cosmological parameters) does not degrade our results beyond $z \approx 0.2-0.3$; most of the constraint on masses comes from low-redshift high-mass clusters. We also explored the possibility of using the CVL and PLANCK catalogs of thousands clusters to analyze the data in $M-z$ cells and found that doing so (if mass bins are sufficiently wide to allow a factor $\sim 3$ uncertainty in cluster mass determination) will add very little to the constraining power of our analysis due to our requirement that each cell contains at least 20 clusters and the fact that clusters in our sample are very much uniform in size and redshift, and hence also in mass. In addition, there is a strong correlation between the mass and redshift of detected clusters. This correlation is most apparent for high-z clusters; when such a cluster is detected, it mostly lies within a narrow mass range just above the threshold for detection. At lower redshifts the mass range of detected clusters increases but the strong M-z correlation persists. Therefore, counting galaxy clusters in redshift-bins essentially amounts to counting clusters in mass bins which is indeed a more direct probe of neutrino mass. The only difference being that cluster mass inference is highly model-dependent while their redshift determination is much cleaner.

The approximate Fisher matrix for cluster number counts reads (Lima & Hu 2004)

$$F^N_{\mu\nu} = \sum_{i,j} N^i_{,\mu}(C^{-1})_{ij} N^j_{,\nu} + \frac{1}{2}\mathrm{Trace}[C^{-1}S_{,\mu}C^{-1}S_{,\nu}] \tag{12}$$

where $C = N + S$ is the total covariance matrix; $N$ is the diagonal Poissonian part while $S$ encodes the correlation between redshift bins and generally has small off-diagonal terms, but is less relevant for our case of wide bins, and more generally when correlations between populations in different bins are negligible. The estimated uncertainty in the parameter $\lambda_\mu$ is then

$$\Delta\lambda_\mu = (F^N_{\mu\mu})^{-1/2}, \tag{13}$$

where we take the square root of the $j$'th Fisher matrix element. The total Fisher matrix that includes cluster number counts combined with either the primordial or lensed CMB is $F^{pr}_{\mu\nu} + F^N_{\mu\nu}$ or $F^{\mathrm{LE}}_{\mu\nu} + F^N_{\mu\nu}$, respectively, and the uncertainty in the parameter $\lambda_\mu$ is similar to that in Eq.(13). To estimate the signal-to-noise $\mathcal{S}/\mathcal{N}$ with which a cluster can be detected in a survey we follow our original work and assume that main sources of noise are instrumental, primary CMB anisotropy, and point source contamination. We assume the performance of optimal matched filters as applied in SSR in order to estimate the abundance of detected clusters on a finely-sampled $M-z$ grid (sampled to the level required for convergence of our constraints on neutrino mass).

## 4 RESULTS

In this work we have adopted the $\Lambda$CDM cosmological model with WMAP-7 best-fit parameters. The cluster population is described in terms of the mass function of Tinker et al. (2008), with IC gas mass fraction described by Eq.(11) and IC gas profile as in Eq.(10). It is the high sensitivity of the halo mass function to neutrino masses (e.g. Brandbyge et al. 2010) that we use as a probe of the total neutrino mass. It is important to note that in this analysis no priors were set on the cosmological parameters, nor on the gas mass fraction (modeled in our analysis with one parameter), except for $H_0$ for which we adopted an uncertainty of 2.5 km/sec/Mpc. In addition, we considered four nuisance parameters that describe possible departures from the Tinker mass function and explored the robustness of $\sigma_{M_\nu}$ to small changes in these parameters ($\alpha_1 - \alpha_4$) assuming that these parameters are known at the 1-10% precision level.

PLANCK specifications are given in Table 1. For $F^{pr}$ and $F^{LE}$ we used all nine frequency bands while for simulating cluster detection for our cluster number counts analysis we assumed only the 100, 143 and 353 GHz bands are used. Our basic results for the neutrino mass uncertainty based on cluster number counts from SZ surveys with the ongoing PLANCK and CVL experiments are presented in Table 2. We show (from left to right) the expected uncertainty on the inferred $M_\nu$ from the primary CMB (both temperature anisotropy and polarization),

lensing extraction (LE) of the CMB, primary CMB and cluster SZ number counts, LE and cluster number counts, and finally the total number of clusters expected to be detected. The cluster mass range we considered is $3 \times 10^{13} M_{\odot} - 3 \times 10^{15} M_{\odot}$, but we verified that the high $\mathcal{S}/\mathcal{N}$ detection threshold that we imposed on the cluster samples guarantees that the detected detected clusters are much more massive than the imposed lower mass bound.

The results presented in Table 2 demonstrate that with cluster number counts alone (and priors based on measurements of the primary CMB power spectrum and the HST prior on $H_0$) neutrino mass uncertainties may be constrained to the $\sim 0.04 - 0.06$ eV range, depending on the details of the SZ cluster surveys. The $\sim 0.04 - 0.06$ eV range brackets our expectations assuming we trust the mass function - a standard practice in this approach. To test the robustness of our estimates to possible deviations from values of the parameters in the analytic representation of the mass function adopted here, we allowed some freedom in these parameters, beyond the fiducial values that were obtained from best-fitting to simulation (Tinker et al. 2008). A few examples that illustrate our findings are as follows: We find that the primordial CMB combined with PLANCK cluster number counts give $\sigma_{M_\nu} = 0.06$ eV (using the Tinker mass function). With a 10% uncertainty in the four mass function nuisance parameters, the uncertainty grows to $\sigma_{M_\nu} = 0.12$. Similarly, the CVL SZ survey will result in $\sigma_{M_\nu} = 0.04$ or $0.11$ eV if the mass function is precisely known or known to only 10% precision, respectively. The conclusion from this is that accounting for mass function uncertainty is particularly important when reliable constraints on neutrino mass are required.

## 5 DISCUSSION

The CMB is perhaps one of the best understood and most model-independent underpinnings of modern cosmology. The near future holds the promise of tightly constraining neutrino mass. However, the capacity of primary CMB alone to constrain $\sim \mathrm{Mpc}$ cosmology is rather limited; even CMB lensing by LSS, a sensitive probe of neutrino masses, takes place on considerably larger physical scales. In addition, standard forecasts of LE performance rely on the assumption that the primordial CMB signal is gaussian, and any nongaussianity present in the data should be attributed to lensing of the CMB. It should be emphasized that the results for neutrino masses derived from CMB and LE reported here, and in other works, always make this simplifying assumption. However, non-gaussianity can also be induced by astrophysical sources. Primordial nongaussianity is yet another source of confusion. On the relevant angular scales secondary CMB signals, such as the thermal and kinematic SZ effect, are known to be present. These are inherently nongaussian and can interfere with LE. If clustering of point sources is important on the relevant angular scales, then it is an additional nongaussian source that could be separated, in principle, from the lensed CMB signal using multifrequency observations, though this requires an accurate modeling of the emitting source, and would in any case be limited by the finite number of frequency channels.

Structure on Mpc scales probes the entire evolutionary history of matter perturbations down to these scales. This is especially relevant to neutrino physics via the effect of neutrino free streaming on these and larger scales. Indeed, Lyman-alpha ($Ly\alpha$) observations can provide additional diagnostic power to that from the CMB on these scales. However, since astrophysical conditions in the $Ly\alpha$ forest are not known very well, it is desirable to consider other probes of clustering on Mpc scales to complement $Ly\alpha$, as well as other traditional probes such as galaxy clustering, shear measurements, etc., as independent probes, and - minimally - to provide us with consistency checks. The possibility of using cluster catalogues to constrain neutrino masses has already been discussed by Wang et al. (2005). More generally, extraction of cosmological parameters, such as $\Omega_b$, $\Omega_\Lambda$, from cluster number counts - in conjugation with other cosmological probes - is widely discussed in the literature (e.g., Holder, Haiman & Mohr 2001, Cunha, Huterer & Frieman 2009, SSR).

Our results, summarized in Table 2, show that the projected uncertainties on neutrino masses lie in the $\sim 0.04 - 0.06$ eV range. This predicted relatively small mass uncertainty is competitive with that predicted in LE analyses.

The most important source of uncertainty in modeling cluster abundance and internal properties is the mass function. Current uncertainties in this basic function were explicitly included in our analysis. Continued extensive cosmological hydrodynamical simulations, e.g. Cunha & Evrard (2009), are likely to result in a significantly more precise determination of this function across the cluster mass range. In contrast, uncertainties stemming from using simple models for the spatial profiles of the gas density and temperature are of secondary importance, simply because these are much-reduced when calculating integrated SZ measures and, more generally, have little effect on cluster detection. After all, the magnitude of the SZ-induced anisotropy is not determined by each of these quantities separately (in the non-relativistic limit that is valid for our purpose here), but rather by the integrated gas pressure along the line of sight.

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| Experiment | $f_{\rm sky}$ | $\nu[GHz]$ | $\theta_b[1']$ | $\Delta_T[\mu K]$ |
|---|---|---|---|---|
| PLANCK | 0.65 | 30 | 33 | 4.4 |
| | | 44 | 23 | 6.5 |
| | | 70 | 14 | 9.8 |
| | | 100 | 9.5 | 6.8 |
| | | 143 | 7.1 | 6.0 |
| | | 217 | 5.0 | 13.1 |
| | | 353 | 5.0 | 40.1 |
| | | 545 | 5.0 | 401 |
| | | 856 | 5.0 | 18300 |

**Table 1.** Sensitivity parameters for Planck: Only the 100, 143 and 353 GHz bands are used in the number counts estimates presented in this work.

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| Experiment | mass function uncertainty % | $\sigma_{M_\nu}[eV]$(prim.) | $\sigma_{M_\nu}[eV]$(LE) | $\sigma_{M_\nu}[eV]$[prim.+N(z)] | $\sigma_{M_\nu}[eV]$[LE+N(z)] | $N_{clus}$ |
|---|---|---|---|---|---|---|
| PLANCK | 0 | 0.43 | 0.15 | 0.06 | 0.06 | 6040 |
| | 3 | | | 0.07 | 0.06 | |
| | 5 | | | 0.08 | 0.07 | |
| | 10 | | | 0.12 | 0.09 | |
| CVL | 0 | 0.29 | 0.05 | 0.04 | 0.03 | 13860 |
| | 3 | | | 0.06 | 0.04 | |
| | 5 | | | 0.07 | 0.04 | |
| | 10 | | | 0.11 | 0.05 | |

**Table 2.** Statistical uncertainty on total neutrino mass from cluster number counts obtained from the PLANCK and CVL SZ surveys. Shown are the expected $1\sigma$ neutrino mass uncertainties. We show the results from CMB alone, LE, CMB+cluster number counts N(z), and LE+N(z). The total cluster number expected to qualify into the sample is shown on the right column.